Plant Foods Hum Nutr (2010) 65:77–82
DOI 10.1007/s11130-009-0149-5

ORIGINAL PAPER

Nutrient Based Estimation of Acid-Base Balance in Vegetarians and Non-vegetarians

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Published online: 7 January 2010

Abstract A first objective of the present study was to estimate the acid-base balance of the food intake in vegetarians and non-vegetarians. A second objective was to evaluate if additional input of specific food items on the existing potential renal acid load (PRAL) list was necessary for the comparison of the two dietary patterns. Thirty vegetarians between the age of 18 and 30 years were matched for sex, age and BMI with 30 non-vegetarians. Based on the 3-days food diaries the acid-base status of the food intake was estimated using the PRAL method. Mean PRAL values as estimated with the standard table yielded an alkaline load of -5,4±14,4 mEq/d in the vegetarians compared to an acid load of 10,3±14,4 mEq/d in the non-vegetarians ($p<0{,}001$). Mean PRAL values as estimated with the extended table yielded an alkaline load of -10,9±19,7 mEq/d in the vegetarians compared to an acid load of 13,8±17,1 mEq/d for the non-vegetarians ($p<0{,}001$). The findings of this study indicate that vegetarian food intake produces more alkaline outcomes compared to non-vegetarian diets. The use of the standard PRAL table was sufficient for discrimination between the two diets.

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Keywords Acid-base balance · Nutrient · Potential renal acid load · Vegetarian

Abbreviations

PRAL	potential renal acid load
NAE	net acid excretion
OA	organic acids
E%	energy %
RDA	recommended daily allowances
BW	body weight

Introduction

The impact of nutrition on different prosperity diseases has been demonstrated extensively, whereas there is strong scientific indication that a diet rich in fruits and vegetables is protective against a wide variety of human diseases [1, 2].

There is a vast body of evidence that food intake affects acid-base balance in the human body. In general a high protein intake has an acidifying effect, while a high fruit and vegetable intake has a more alkaline effect and as such reduces the acid load [3, 4].

One of the most striking effects of a dietary acidic overload may result in demineralisation of the bone. Indeed, already in 1968 Wachman and Bernstein proposed that dietary intake is related to the development of osteoporosis through the regulation of the acid-base balance [5]. Moreover, in the multi-country study of women, above 50% the incidence of hip fractures as a function of vegetable and animal protein intake was studied. A positive relation was found between a high consumption of animal proteins and hip fractures [6]. According to Frassetto et al. [7] and Buschinsky [8], consumption of alkaline-forming foods, such as fruits and vegetables, may be important in buffering the acid load imposed by the ingestion of protein rich foods, such as meat. Barzel and Massey [9] found that the average American diet, which has a high protein content and a poor amount of fruits and vegetables, causes a high production of acids. Nutrients found in abundance in fruits and vegetables may be protective for bone health because of their alkaline-forming properties [10]. A study of Vormann and Goedecke [11] showed that a disturbed acid-base balance may contribute to the symptoms of low back pain. The intake of an alkaline multimineral preparate reduced the pain symptoms in these patients significantly.

Remer and Manz [12] showed that diet has an impact on urine-pH and the net "dissidence" of acid or net acid excretion (NAE). Diets with a low protein quantity (49 g/day), with a moderate protein quantity (95 g/day) and with a high protein quantity (120 g/day) were studied. The average urine-pH was respectively was 6.7 for the low protein diet, 6,0 for the moderate protein diet and 5,5 for the high protein diet. This study clearly showed that the composition of a diet can influence to a large degree the acid-base balance [12].

Based on the relation between food intake and urine-pH a calculation model was developed to evaluate the acid charge of food intake and to predict the potential renal acid load (PRAL) based on the protein, phosphorus, potassium, magnesium and calcium content of different individual food items [13].

PRAL is a measure of the acid- or base-forming potential of commonly consumed foods and beverages, with negative values reflecting an excess of base-forming potential and positive values indicating an excess of acid-forming potential. Specific intestinal absorption rates of contributing nutrients, ionic balances for calcium and magnesium, and grade of dissociation of phosphate at pH 7,4 are accounted for when converting daily nutrient intakes into milli-equivalents (mEq) of either H^+ or OH^-.

Several studies have indicated differences in the composition of the diet between vegetarians and non-vegetarians, with vegetarians having a lower daily protein intake and a higher fruit and vegetable intake compared to non-vegetarians [14, 15]. Vegetarian diets may offer nutritional advantages such as: lower total energy intake, lower cholesterol and animal protein, and higher quantities of carbohydrate, fibre, magnesium, potassium and antioxidants [16–19]. According to the most recent position stand of the American Dietetic Association and Dietitians of Canada, a vegetarian diet may have a positive impact on maintaining the acid-base homeostasis compared to a non-vegetarian diet [20].

Up to now few studies compared the acid-base balance in the diet of vegetarians versus non-vegetarians [14, 21, 22].

A first objective of the present study was to estimate the acid-base balance in the food intake of vegetarians and non-vegetarians. A second objective was to evaluate if additional input of specific food items on the existing potential renal acid load list was necessary for the comparison of the two dietary patterns.

Materials and Methods

Thirty lacto-ovo-vegetarians (vegetarian for at least 5 years), between the age of 18 and 30 years (mean age, 23±2 years) were recruited and matched according to sex (8 men and 22 women), age, and BMI with 30 non-vegetarians (mean age, 24±3 years), (Table 1). Body weight and body height were self reported and used to determine the BMI. All subjects completed a 3-days food diary (3 consecutive days, 2 week days and 1 weekend day). The acid-base status of the food intake was estimated using the PRAL method as proposed by Remer and Manz [23]. Since we were working with a vegetarian population, consuming several food items not listed in the standard PRAL table, we used additional input (for 358 food items) regarding acid and base balance based on the protein, phosphorus, potassium, magnesium and calcium content of the food items derived from the Belgian Nutrient Composition Table [24]. The PRAL-value of each food item was estimated as follows:

PRAL=0,49 × protein (g/d) +0,037 × phosphorus (mg/d)-0,021 × potassium (mg/d)-0,026 × magnesium (mg/d)-0,013 × calcium (mg/d) [23]. Table 2 shows examples of estimated PRAL-values of typical products consumed by vegetarians versus non-vegetarians. The net acid excretion (NAE) can be estimated using the PRAL values and an estimation of the amount of organic acids (OA). According to Remer [3], a linear relation exists between OA and body weight (OA=0,66 × body weight). As a consequence NAE can be estimated using the following equation: NAE = PRAL + OA.

Informed consent from the participating subjects was obtained.

To process and analyse the data, "SPSS 16.0" and "Microsoft Windows Excel" was used. Normality was tested using the Kolmogorov-Smirnov-goodness-of-fit-test. For differences between both groups, the unpaired *t*-test was used. For differences within groups, the paired *t*-test was used. The statistical significance level was set at 0,05.

Table 1 Height, weight and BMI of vegetarians and non-vegetarians

	Vegetarians (n=30)	Non-vegetarians (n=30)	p
Height (m)	1,72±0,09	1,72±0,08	0,805
Weight (kg)	64,14±10,26	64,51±10,65	0,892
BMI (kg/m^2)	21,61±2,14	21,82±2,87	0,749

Table 2 Examples of calculated PRAL-values of typical products consumed by vegetarians versus non-vegetarians (mEq/100 g)

Vegetarian	PRAL-value	Non-vegetarian	PRAL-value
Lentile soup	-1,4	Chicken soup	2
Quorn burger	7,8	Chicken burger	7,3
Quorn mince	8,7	Meatball	10,2
Soy burger	-2,1	Hamburger	10,2
Soy oil	0	Butter	0,4
Tofu burger	-2,2	Tuna	12,2
Yofu soy	0,1	Yoghurt	0,5

Results

Total energy intake did not differ between vegetarians and non-vegetarians (p=0,484), (Table 3). Energy distribution for the different macronutrients was closer to the recommendations in the vegetarians compared to the non-vegetarians. The vegetarians had a carbohydrate intake of 56,3±7.0 E% (Energy%) while the non-vegetarians had an intake of 50,6±9.1 E% (p=0,009). The mean protein intake values were 13.8±1.9 E% in the vegetarians versus 16,5± 3.5 E% in the non-vegetarians (p=0,001). The fat intake did not differ between the vegetarian and the non-vegetarian subjects (p=0,202, p=0,256).

Calcium, phosphorus, magnesium, potassium and sodium intake were all within the recommended quantities in the vegetarians and the non-vegetarians (Table 3). Potassium (p= 0,014) and magnesium (p=0,003) intake were significantly lower in the non-vegetarians compared to the vegetarians (Table 3). The Ca/P-ratio was significantly (p=0,033) lower in the non-vegetarians (Ca/P=0,6±0,2) as compared to the vegetarians (Ca/P=0,8±0,4) (Table 3).

Table 4 shows the consumed food groups in the vegetarians and the non-vegetarians. The vegetarians had a significantly (p<0,001) higher fruit and vegetable consumption. The non-vegetarians had a meat consumption of 186± 92 g/day, compared to a meat replacers consumption of 77 g/day (43±25 g/day acid forming meat replacers and 34± 41 g/day base forming meat replacers) in vegetarians (Table 4). The consumption of acid forming drinks (e.g. soft drinks) was significantly (p<0,001) lower in vegetarians, while base forming drinks consumption was significantly (p<0,001) higher. Grains, pasta, bread, milk, dairy products, potatoes and sweets were consumed in comparable quantities.

The average PRAL was significantly higher in the non-vegetarians compared with the vegetarians (p=0,001), (Table 5). The PRAL of the vegetarian diet showed an average alkaline value of -5,4±14,4 mEq/d using the standard PRAL-list and a value of -10,9±19,7 mEq/d when using the extended list. On the contrary the omnivorous diet had an acidifying value of 10,3±14,4 mEq/d when using the standard PRAL-list or 13,8±17,1 mEq/d when using the extended list. Since they were matched for body weight the average "dissidence" of diet independent acids or organic acids (OA) was comparable in the vegetarians (42,3± 7,2 mEq/d) compared to the non-vegetarians (42,6± 7,0 mEq/d). The addition of organic acids resulted in NAE-values of 36,9±16,7 mEq/d using the standard PRAL-list or 31,4±21,4 mEq/d using the extended list in the vegetarians, and 52,9±18,7 mEq/d using the standard PRAL-list or 56,4± 21,2 mEq/d using the extended list in the non-vegetarians. A significant difference was observed when comparing standard versus extended PRAL- (p=0,019) and NAE- (p=0,019) calculations within the vegetarian group.

Discussion

A comparison of the quantity and quality of both diets showed a similar total energy intake between matched pairs

Table 3 Daily total energy, macronutrient and mineral intake in vegetarians and non-vegetarians

	RDA	Vegetarians (n=30)	Non-vegetarians (n=30)	p
Total energy (kcal)	2100–2600	2110±460	2215±678	0,484
Protein (E%)	10–15	13,8±1,9	16,5±3,5	0,001
Carbohydrate (E%)	55–75	56,3±7,0	50,6±9,1	0,009
Fat (E%)	15–30	28,6±6,3	30,9±7,5	0,202
Protein (g)	52 (0,8 g/kg BW)	71±16 (1,1 g/kg BW)	89±31 (1,4 g/kg BW)	0,01
Carbohydrate (g)	320	291±73	273±96	0,417
Fat (g)	64	68±23	77±31	0,256
Na (mg)	575–3500	2733±1145	3210±1234	0,126
K (mg)	2000–4000	3479±1036	2868±824	0,014
Mg (mg)	330–420	412±151	305±114	0,003
Ca (mg)	900	989±383	871±436	0,272
P (mg)	800	1376±438	1473±566	0,463
Ca/P-ratio	>1	0,8±0,4	0,6±0,2	0,033

BW body weight, *RDA* recommended daily allowances

Table 4 Intake of different food groups in vegetarians and non-vegetarians (g/day)

Food groups (g/day)	Vegetarians (*n*=30)	Non-vegetarians (*n*=30)	p
Grains	42±15	38±20	0,385
Pasta	48±23	42±21	0,296
Bread	172±35	175±42	0,765
Vegetables	268±45	185±38	<0,001
Fruit	283±60	120±65	<0,001
Meat	0	186±92	
Milk and dairy products	180±152	215±185	0,427
Potatoes	70±53	91±50	0,120
Sweets	117±43	138±58	0,117
Acid forming meat replacers	43±25	0	
Base forming meat replacers	34±41	0	
Acid forming drinks	120±61	204±75	<0,001
Base forming drinks	1675±253	1130±315	<0,001

of vegetarians and non-vegetarians (p=0,484). The vegetarians approximated better the recommended macronutrient energy distribution compared to the non-vegetarians with significant differences for protein E% (p=0,001) and carbohydrate E% (p=0,009). Calcium, phosphorus, magnesium, potassium and sodium intake were all within the recommended quantities in the vegetarians and the non-vegetarians. Potassium (p=0,014) and magnesium (p=0,003) intake was significantly lower in the non-vegetarians compared to the vegetarians. Also the Ca/P-ratio was significantly (p=0,033) lower in the non-vegetarians. The Ca/P-ratio should reach 1, ideally 1,3 [25], while a Ca/P-ratio below 0,5 is considered critical. These results indicate a more balanced nutritional intake in vegetarians and corroborate the statements on vegetarian and plant based diets [16–18]. Nevertheless, compared to the most recent food consumption survey in Belgium [26] the non-vegetarian subjects of the present study had better nutritional habits, indicating that these omnivorous subjects can be considered a more health conscious group as compared to a representative sample of the Belgian population.

According to Kerstetter and Allen [27], protein increases calcium loss by about one milligram of calcium per gram of protein, but it also stimulates bone building. These conflicting effects mean that increased protein intake can have either a beneficial or an adverse effect on overall calcium balance, depending on background intakes of protein and other nutrients, genetic background and age. As protein from plants is usually accompanied by much more potassium compared with animal protein, there is good reason to meet protein needs preferably from plant sources. Alkaline foods (typically high in potassium relative to protein) cause an augmented blood pH, thus protecting bone by increasing its resistance to demands for more calcium to be released in the blood [27, 28].

According to Remer and Manz [13] chronic metabolic acidosis can be caused by a constant raised NAE of 100 mEq/day (or PRAL 60 mEq/day), which may result in maximum renal stimulation of acid. This is the physiological border where plasma bicarbonate levels decrease and the largest source of alkali, the bone structure, will release large quantities of minerals to buffer the exuberant acid production [13].

Although the mean NAE-value of the non-vegetarians (56.29±21.19 mEq/day) was inducing a considerable acid load, these values remain far below this physiological limit of 100 mEq/day. The calculation of the potential renal acid load allows an estimation of the consequences of diet on the acid-base balance [12]. It seems possible to use PRAL-values to indicate whether certain groups have larger or smaller risks of developing symptoms related to acid-base

Table 5 Standard versus extended PRAL- and NAE-values for vegetarians and non-vegetarians in mEq/d

	Vegetarians (*n*=30)	Non-vegetarians (*n*=30)	p (vegetarians-non-vegetarians)
Standard PRAL calculator	-5,4±14,4	10,3±14,4	<0,001
Extended PRAL	-10,9±19,7	13,8±17,1	<0,001
p (standard-extended PRAL)	0,019	0,070	
Standard NAE	36,9±16,7	52,9±18,7	<0,001
Extended NAE	31,4±21,4	56,4±21,2	<0,001
p (standard-extended NAE)	0,019	0,070	

unbalance. Although below the physiological limit, the omnivorous diet seems to put higher pressure on the buffering systems. This may increase the risk for compensation from the calcium resources of the body. In this study the base-forming character of a vegetarian diet was mainly due to the larger consumption of fruits and vegetables, whereas the high meat consumption and acid forming drinks in non-vegetarians could be considered the responsible acidifying components. Tables 2 and 5 explain the fact that the use of the standard PRAL nutrient table was sufficient for discrimination between the two diets. The additional input of specific food items on the existing PRAL list was mainly necessary for evaluating the impact of the food items specific for a vegetarian diet such as meat replacers. Meat substitutes, particularly the acid forming ones, were consumed in relatively small amounts by the vegetarians as compared to the meat consumption in the non-vegetarians.

The present study is in line with the hypothesis that non-vegetarians have a higher risk for chronic metabolic acidosis compared to vegetarians. The acid load in the non-vegetarians was of the same order of magnitude as reported for other studies in industrialized countries where the overall usual diet provided a daily excess of about 50 mEq/d which must be excreted by the kidneys [1, 29]. Apparently, in the omnivorous subjects the souring potential of protein was not countered by an additional intake of base producing minerals such as potassium and magnesium [13]. Limitations of the present study are the relatively small sample studied and the absence of direct measurement of urine pH which could, according to Remer [3], confirm our estimations. Further research is required in order to shed light on the mechanism of shifts in the acid-base balance in different dietary populations.

In conclusion, the present results corroborate the findings reported by Remer [3], indicating that vegetarian food intake bring about more alkaline outcomes compared to non-vegetarian diets. The use of the standard PRAL table proved to be sufficient for discrimination between the two diets. The additional input of specific food items on the existing PRAL list was mainly necessary for the food items specific to a vegetarian diet such as meat replacers. These meat replacers, especially the acid forming ones, were consumed in small amounts by the vegetarians compared with the meat consumption in non-vegetarians, and did not affect the NAE values.

Acknowledgements We express our thanks to all the individuals who volunteered in this study.[1]

[1] This study has been partially presented in poster form in 2008, at the V[th] International Congress on Vegetarian Nutrition, Loma Linda, California, USA.

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